Requirements for Offshore Grid Connections

in the

Grid of TenneT TSO GmbH

Bernecker Straße 70, 95448 Bayreuth

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1. Introduction
The following requirements pertain to the grid connections of offshore wind parks in seas, which are referred to here as offshore grid connections.

Except for the deviations and amendments contained herein, the same requirements for the offshore connections basically apply as for all other connections in the grid of TenneT TSO GmbH (TTG), as defined in "Netzanschlussregeln Höchstspannung" ("Grid Code Extra-High Voltage") (NAR, Updated: 01.12.2012).

The fulfilment of the NAR and of the requirements for the offshore grid connections are an essential condition at the grid connection point (see terminology) to ensure a secure operating system, not only for the offshore wind parks, but also for the grid onshore.

2. Legal Framework and Scope
The law which came into effect in December 2006 to accelerate the planning process for infrastructure projects, that is, §17 sec. 2a Energiewirtschaftsgesetz (Energy Industry Act), requires transmission system operators (TSO) to lay out and operate grid connection cables up to the substations for generating plants which are erected in the North and Baltic Seas, and which comply with the Erneuerbare-Energien-Gesetz (Renewable Energy Sources Act).

The amended requirements or deviations as set forth herein apply, in combination with the NAR for the grid connection point.

3. Terminology
Generating plant
A generating plant (offshore wind park) can comprise of one or more generation units. It includes all auxiliary system and secondary equipments.

Generation unit
A generation unit consists of a single wind energy turbine with the corresponding generator, generator transformer and busbars in the turbine tower.

Grid connection system
The term grid connection system denotes the whole connection between the grid coupling point and the connectee. Depending on the connection design, the grid connection system can consist of partial DC transmission (HVDC) or a direct AC connection.
Grid connection point
The grid connection point is the point at which the connectee’s equipment is connected to the grid connection system. For the offshore wind parks this is the offshore cable sealing end of the grid connection system. Concurrently, it represents the ownership boundary between the connectee’s facility and that of the transmission system operator (TSO).

Grid coupling point
The grid coupling point is the point at which the grid connection system of the offshore-wind park is connected to the onshore transmission grid of the TTG.

Abbreviations for the Voltage Levels
HV – high voltage
MV – medium voltage
LV – low voltage (generator voltage)

4. Requirements at the Grid Connection Point

4.1. Voltage and Frequency Characteristics
Supplementary to the NAR section 3.1.7, the following nominal voltage is specified for the grid connection point:

- 155 kV: continuous operating voltage of 140 - 170 kV

In single cases, other nominal voltages are acceptable after clearance with TTG.

The nominal frequency for the offshore grid connection is 50 Hz as in the NAR.

In contrast to the specified frequency range as specified in the NAR section 3.1.7, an extended range is applicable:

- limited to up to 10 seconds: 46.5 and 53.5 Hz (fig. 3a)

4.2. Neutral Point Connection and Dimensioning of the Generating Plant Transformers
Supplementary to the NAR section 3.1.8 the following applies:

The grid connection system, including the metallically connected parts, operates with a low resistance neutral point (solidly earthed).

To decouple the zero phase sequence components, improve the symmetry of the line-to-earth- voltage during short circuits, and avoid transmitting odd-numbered harmonics, divisible by three, the HV/MV transformers are to be implemented in the vector group YN/d5.

All the neutral points at the high voltage side of the HV/MV transformers must be non-switchable with a direct connection to earth.
The HV/MV transformers must be equipped on their HV side with a tap changer to provide +/- 13% variation in +/- 6 steps. The tap changing function is to be integrated within the control design of the grid connection. Both the control design and settings are subject to TTG approval. A transmission ratio of 155/31.5 kV is recommended.

4.3. Active Power Output

Complementary to the NAR section 3.2.6.2, following system protection functions/emergency control actions are to be implemented in the generation units:

1. All generation units must be disconnected from the grid upon reaching a frequency at the grid connection point of less than 46.5 Hz or greater than 53.5 Hz and after a time delay of 300 ms.

2. All generation units must be disconnected from the grid upon reaching a frequency at the grid connection point of less than 47.5 Hz or greater than 51.5 Hz and after a time delay of 10 s.

Hence, complementary to the NAR, following figure 3a presents the duration of operation of a generating plant in dependency to the voltage at the grid connection point and to the nominal frequency.

Figure 3a “Offshore”:
Duration of operation of a generating unit in dependency of the voltage at the grid connection point and of the nominal frequency
Figure 3b “Offshore”:
Basic Requirement for the active power output of a generation unit in dependency to the frequency and to the duration of operation

There are no requirements for the areas beyond the maximum time values of the respective frequency regions. Nevertheless, it is assumed that the maximal possible active power is available for delivery.

After a disturbance with zero residual voltage at the grid connection point a restart of the generation plant with maximum 10% per minute of the maximal installed active power is allowed.

4.4 Reactive Power Exchange and Voltage Stability

At the grid connection point with a nominal voltage of 155 kV the following requirements apply, in contrast to the figure 4 of the NAR:

Figure 4a “Offshore”:
Operating range of a generation plant in dependency to the voltage and the power factor with unrestricted active power output
Regarding the reactive power supply capability or the power factor, the diagram in figure 4 represents minimum requirements. A reactive power supply capability beyond the range of these requirements is allowed, but is not defined or quantified in the present connection requirements.

The generating plant is expected to set any working point inside the green boundary lines within maximum 30 s.

The reactive power supply according to figure 4a in a frequency range of 47.5-51.5 Hz must be unrestrictedly possible. The reactive power supply may be shortened beyond this frequency range, due to founded technical restrictions at the generating unit.

The following P/Q-operation range as represented by figure 4b applies for the static operation of the respective generating units. This specification is valid within a voltage variation range of ±5 % of the nominal voltage. The values for the active power, reactive power and voltage refer to the low voltage side of the machine transformer. Shortening is allowed beyond the defined voltage variation range in case of justified technical restrictions at the generating unit.

**Figure 4b “Offshore”:**

Minimum requirements for the P/Q-operation range of a generation unit within the voltage range of +/- 5 % \( U_N \) (at the generation unit)

In the case that the reactive power delivery by the entire generation plant at the grid connection point as required in figure 4a, with a P/Q capability of the generating units corresponding to figure 4b can not be fulfilled totally for a power generation range above 90 % of the nominal power of the generating plant, the necessity of external additional reactive power sources or an extension of the requirements according to figure 4b will be decided project specifically in clearance with TTG.
It is recommended to fully compensate the internal capacitive charging current of the offshore grid, for example, by means of a switchable reactance coil. This compensation is needed for the case the generating plant has to be supplied by emergency generating units during an outage of the grid connection system.

The compensation units are to be integrated within the control design of the grid connection system. Both the design and control settings of the compensation units are subject to TTG approval.

4.5 Characteristics of Generating Plants during Grid Failures

Supplementary to the requirements defined in NAR section 3.2.6.2, the following characteristics of the generating plants at the grid connection point apply:

The voltage support of the generation unit is to be activated when a voltage drop of more than 5% of the rms value of the generator voltage occurs.

The voltage support must start within 20 ms after fault detection.

Based on the established requirements as described herein, the following applies for figure 7 of the NAR:

Figure 7 “Offshore”:
Principle of the voltage support by each generating unit during grid failures. In individual cases, the gradient of the voltage support can be changed (Reactive current droop with k > 2)
4.6 Active Power Reduction during Overfrequency

Figure 8 of the NAR is replaced for offshore connections by the following:

\[ \Delta P = 20 \cdot P_M \cdot \frac{50.2 \text{ Hz} - f_{\text{grid}}}{50 \text{ Hz}} \quad \text{when } 50.2 \text{ Hz} \leq f_{\text{grid}} \leq 52.7 \text{ Hz} \]

- \( P_M \): currently available power
- \( \Delta P \): Power reduction
- \( f_{\text{grid}} \): Grid frequency

In the range 47.5 Hz \( \leq f_{\text{grid}} \leq 50.2 \text{ Hz} \) no restriction

Figure 8 “Offshore”:
Active power reduction in case of overfrequency

In a frequency range of 47.5 – 50.2 Hz, the generating units must be able to unrestrictedly feed active power into the grid. Below a frequency of 47.5 Hz the active power supply may be shortened due to justified technical restrictions.

Above a frequency of 50.2 Hz, as defined in section 3.3.2 of the NAR, a frequency dependent active power reduction is required. The technical solution implemented for this purpose must achieve a maximal power variation gradient of 25% of the currently available active power of the generation unit per second.
5. Protection Devices and Automation

Supplementary to NAR sections 3.2.7 and 4.1, these specified requirements for the offshore connections apply:

At least two independent protection systems must be implemented. Both protection systems operate in first time protection zone and under different protection principles (for example, differential and distance protection). For the two protection systems different hard and software platforms must be implemented. In addition, transformers and reactive coils are equipped with a Buchholz relay.

Busbars in the generating plants are to be protected in first time protection zone.

Short fault clearance times are to be maintained throughout the whole protection zone. In case of a circuit breaker failure (also within the generating plant), a disconnecting time limit of 250 ms must be reached.

In the generating plant a direct longitudinal unsymmetrical state of over 20% of the nominal operation current should automatically be eliminated with a disconnecting time of up to 500 ms.

The design and the settings of this protective function are subject to TTG approval.
6. Data Exchange

6.1 Basic design

To carry out the steady state and dynamic grid connection tests, the data and documents required in appendix E, table 2 of the NAR, must be made available to TTG in the form of a so-called basic design.

This basic design supplies mandatory detailed information on the generating plant.

6.2 Extended Data Range for the Grid Connection Test

To carry out the grid connection test on offshore wind parks, additional data and documents are to be submitted:

a) Design for the voltage and frequency control of the generating plant.

b) For the steady state study:
   - documents in accordance with appendix E, table 2 (basic design)
   - System data in .dtf Format for the network area between the grid connection point and the generation units including a schematic diagram.

c) For the dynamic system study:
   - proof of the behaviour of the generating plant and/or of the generation units during failures in the grid connection and/or at the generator terminal
   - detailed dynamic NETOMAC model including:
     - an illustration comprising all essential features of the wind park and the dynamic behaviour of the wind turbines for the grid connection point
     - all limitations of the equipment, voltage and frequency control within the wind park
     - modelling of transformers
     - modelling of cables
     - modelling of compensation units (reactive coils, capacitors, active compensators, etc.)
     - Proof of verification that the model correlates with the actual generation unit.

The attached table T3: Offshore Wind Farms (OWF) – Grid Connection further explains the requirements for data exchange.
### Table T3: Offshore Windfarms (OWF) – Grid Connection

Minimum scope of the technical information and documentation to be exchanged between TenneT TSO GmbH and connection enquiring partner (planers or operators of offshore power plants)

<table>
<thead>
<tr>
<th>Project Phase</th>
<th>Party concerned</th>
<th>Documentation/Data to be provided</th>
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</table>
| Feasibility                  | TSO                    | - Grid connection code (‘NAR’) and requirements for offshore grid connections to the grid of the TenneT TSO GmbH (‘ASN’)  
- Grid equivalent (min. and max. short circuit current and series impedance at the grid connection point (‘NAP’) (definition according to NAR and ASN) or at the grid coupling point (‘NVP’) (definition according to NAR and ASN)  
- OWF standard configurations and connection concepts (TSO recommendations for the OWF layout including a representation of the asset boundaries)  
- Description of the technical interfaces, responsibilities and standard concepts (incl. TSO-secondary systems) on the NAP  
- Directives for the report on the steady state grid calculations                                                                                                                                 |
| Connection applicant         | Power plant data       | - Submission of a draft of the OWF grid connection concept (Single Line Diagram) including key data of the main components\(^1\)  
- Installed capacity at initial system energisation, further development steps, final state at commissioning  
- Capacity for auxiliary power connection and start-up                                                                                                                                 |
| TSO                          | Power plant data and   | - Description of the project-specific requirements for the power generating system at the grid connection point  
- In case of a DC-Connection, preliminary indication of the location of the HVDC offshore converter station                                                                                                                                 |
| OWF-grid connection concept  | OWF                    |                                                                                                                                                                                                                                    |

\(^1\) The main components and their key data include generators with designation of the type, rated voltage, voltage range, rated apparent power, power diagram, \(x_d\) and \(x_d^*\); Transformers with designation of their rated apparent power, rated voltages, transformation ratio, vector group, short circuit voltage and control range; Specification of the auxiliary power; Specification of the available devices for series and shunt compensation; lines and cables data including types and lengths; description of the normal switching state
<table>
<thead>
<tr>
<th>Project Stage</th>
<th>Party concerned</th>
<th>Documentation/Data to be provided</th>
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</table>
| Steady state grid calculations and compliance tests                         | Connection applicant     | - Contribution to the steady state short circuit current of the TSO’s grid as well as data for load flow and short circuit current calculations  
  - Report on the steady state grid calculations  
    - Notes on the content of the report  
      - Evidences of the fulfilment of the system requirements of the TSO at the NAP  
      - Real measured power diagram of the used wind turbine generator taking into account all relevant influencing factors and parameters  
      - Schematic diagram of the OWF-layout  
      - List of all grid components including their denomination and their nominal parameters for the calculation of the load flow  
      - OWF-grid data in *.dtf file format for the region between the NAP and the generating units including the schematic diagram |
|                                                                              | TSO                      | - Pointing out project-specific requirements for the power generation system at the grid connection point  
  - In case of a DC-connection preliminary indication of the seaward location of the HVDC converter station |
| Review and definition of the OWF electrical design and grid connection concepts | Connection applicant     | - Submission of the final and binding OWF grid connection concept (Single Line Diagram), approved by the TSO, including key data of the main components (for main components see footnote on page 1)  
  - OWF protection concept and control strategies for the entire power generating system  
  - Realisation concept for the system automatics or emergency control strategy  
  - Submission of the auxiliary power supply and emergency power supply concept |
|                                                                              | TSO                      | - Review and approval of the final grid connection concept of the OWF  
  - Description of the project-specific requirements for the power generating system at the grid connection point  
  - Final and binding description of the technical interfaces, areas of responsibility and standard concepts (incl. TSO-secondary systems) at the NAP  
  - Delivery of the planning and design documents for the technical interfaces between the TSO and the OWF (Samples circuit diagrams, address structure, interoperability, etc.)  
  - Preliminary information of the power rating of the AC cable compensation (shunt reactor) if required |
<table>
<thead>
<tr>
<th>Project Stage</th>
<th>Party concerned</th>
<th>Documentation/Data to be provided</th>
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</thead>
<tbody>
<tr>
<td>Transients calculations (switching actions)</td>
<td>Connection appli-</td>
<td>▪ Alignment on the scope and content of the investigations</td>
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<tr>
<td>ciant</td>
<td>TSO</td>
<td>▪ Alignment on the scope and contents of the investigations</td>
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<td>▪ Measurements report(s) to determine the electrical capabilities of the generating units</td>
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<td>▪ Report on the dynamic grid calculations</td>
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<td>Notes on the content of the report:</td>
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<tr>
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<td></td>
<td>o Verification and evidence to meet the system requirements and to the implementation of the realistic and requested protection and control functions in the power generating units and in the power generating plant respectively</td>
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<td>o Results of the grid studies and evidence of fulfilment of the NAR in particularly §§ 4.5 and 4.6 of the ASN and Figure 6 of the NAR</td>
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<td>o Simulation of different operating conditions (scenarios); i.e.: grid faults with different voltage dips level at the connection nodes of the power generating units</td>
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<td>o Simulation of the behaviour of the power generation units and of the power generating plants during over- and under-frequency</td>
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<td>o Graphical representation of the relevant parameter values</td>
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<td>o Precise and detailed description of the system modelling and of the simulation conditions</td>
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<td>o Evidence of the matching of the simulated behaviour with the real measured behaviour of the power generating units</td>
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<td></td>
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<td>o Detailed report and assessment of the simulation results</td>
</tr>
<tr>
<td>Dynamic grid calculations and compliance tests</td>
<td>Connection appli-</td>
<td>▪ Delivery of a dynamic model of the power generating unit and power generating plant according to ASN (delivery after common agreement between TSO and connection enquiring partner on the behaviour of the power generating units and power generating plants on the basis of real measurements and grid calculations/investigations)</td>
</tr>
<tr>
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<td>ciant</td>
<td>▪ Optimisation and adjustments of the grid connection concept and control strategies with regard to the fulfilment of the TSO requirements if required</td>
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<td>▪ Pointing out the project-specific requirements for the power generating system at the grid connection point</td>
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<td>▪ Assessment of the report to dynamic grid calculations</td>
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<td>▪ Assessment and review of the implementation of the requirements and functionality of the delivered OWF models</td>
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<tr>
<td></td>
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<td>▪ Approval of the system dynamic grid calculations and system compliance</td>
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2 Specification and Scope of these Studies must be agreed with the TSO
<table>
<thead>
<tr>
<th>Project Stage</th>
<th>Party concerned</th>
<th>Documentation/Data to be provided</th>
</tr>
</thead>
</table>
| Project development     | Connection applicant     | ▪ Detailed alignment on the technical interfaces, responsibilities and concept strategies at the NAP with the TSO  
▪ Information exchange on the scope of deliveries, services, time schedule and HSE-management between TSO and connection enquiring partner |
|                         | TSO                      | ▪ Detailed alignment on the technical interfaces, responsibilities and concept strategies at the NAP with the connection enquiring partner  
▪ Information exchange on the scope of deliveries, services, time schedule and HSE-management between TSO and connection enquiring partner |
|                         | Connection applicant     | ▪ Determination of the operation management strategies and responsibilities between the connection applicant and the TSO  
▪ Alignment on the sequence and scope of the necessary commissioning tests with TSO  
▪ Filled questionnaire „Nachhaltige Inbetriebnahme von OWPs“  
▪ Alignment on the program of commissioning and time schedule  
▪ Safeguarding of the availability of the complete power plant (OWF) system documentation (construction plans, circuit diagrams, documentation on primary technology and secondary systems etc.) at the NAP  
▪ Evidence of a NAR compliant power plant behaviour at the NAP (Test protocols and metrological certificate from the commissioning operation) |
| Commissioning tests and plant commissioning | TSO                      | ▪ Determination of the operation management strategies and responsibilities between the connection enquiring partner and the TSO  
▪ Alignment on the sequence and scope of the necessary commissioning tests with TSO  
▪ Handover of the directive „Nachhaltige Inbetriebnahme von OWPs“  
▪ Safeguarding of the availability of the complete documentation (construction plans, circuit diagrams, documentation on primary technology and secondary systems etc.) of the TSO equipment an the NAP  
▪ Grid connection contract including technical specification and agreement on operation management subjected to the fulfillment of the TSO requirements during the commissioning operation  
▪ Approval to power plant initial start-up of commissioning operation  
▪ Approval for continuous operation after confirmation of fulfillment of the requirements of the TSO and if applicable the realization of updates and amendments. |